

## DESCRIPTION

LINEAR MOTOR

## 5 TECHNICAL FIELD

The present invention relates to a linear motor, more particularly relates to a linear motor able to use a stacked member comprised of a plurality of magnetic sheets stacked together as a stator (platen).

## 10 BACKGROUND ART

Explaining the principle of a Sawyer linear motor, as shown in FIG. 12, it is comprised of a platen (stator) 10 comprised of a magnetic thick plate on whose surface is repeatedly formed platen dots D at a spatial period of the dot pitch P and a movable member (traveling member) 20 comprised of a permanent magnet M for generating a bias magnetic flux, first and second yokes Y1 (Y2) bonded to the magnetic pole surface to be arranged in parallel to the direction of advance and provided with first and second branched magnetic path legs A and A' (B and B'), series-connected first and second A-phase excitation coils CA and CA' wound around the first and second branched magnetic path legs A and A' of the first yoke Y1, series-connected first and second B-phase excitation coils CB and CB' wound around the first and second branched magnetic path legs B and B' of the second yoke Y2, and two pole teeth (projecting poles) KA and KA' (KB and KB') formed at each of

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the bottom ends of the first and second branched magnetic path  
legs A and A' (B and B') and arranged in the direction of advance at  
intervals of  $1/2$  of the dot pitch P. Here, each branched magnetic  
path leg may be formed with only one pole tooth, but in the event  
of several, the spatial phase held with respect to the closest dots of  
the platen dots D is the same. Further, the interval between the first  
branched magnetic path leg A (B) and second branched  
magnetic path leg A' (B') is set so that the spatial phases with  
respect to the closest dots are shifted in the direction of advance by  
exactly  $P/2$ . Further, the interval between the second branched  
magnetic path leg A' and the first branched magnetic path leg B is  
set so that the spatial phases with respect to the closest dots are  
shifted in the direction of advance by exactly  $P/4$ .

The movable member 20 has a pressurized air ejection port  
and floats slightly above the surface of the platen 10 by blown  
pressurized air. As shown in FIG. 12A, if a B-phase current of the  
illustrated polarity is flown through only the terminals of the first and  
second B-phase excitation coils CB and CB' of the second yoke Y2,  
not only the bias magnetic flux due to the permanent magnet M,  
but also the alternating magnetic flux due to the second excitation  
coil CB' are superposed and strengthened to generate a  
concentrated magnetic flux portion a in the air gap between the  
pole teeth KB' of the second branched magnetic path leg B' and  
the closest dots D1 and D2 and strongly magnetically draw the pole  
teeth KB' to the closest dots D1 and D2. Also, an alternating

magnetic flux is applied to the pole teeth CB of the first branched magnetic path leg B in a direction canceling out the bias magnetic flux, so an extinguished magnetic flux portion b is formed. On the other hand, the magnetic flux comprised of the concentrated magnetic flux from the second branched magnetic path leg B' of the second yoke Y2 branched via the inside of the platen 10 passes through the first and second branched magnetic path legs A and A' of the first yoke Y1, but the pole teeth KA of the first branched magnetic path leg A are delayed in the direction of advance by exactly  $P/4$  with respect to the closest dots D15 and D14. Therefore, the closest dots D15 and D14 pull the pole teeth KA in the direction of advance by one branched magnetic flux and the pole teeth KA' of the second branched magnetic path leg A' proceed in the direction of advance by exactly  $P/4$  with respect to the closest dots D10 and D9 due to the other branched magnetic flux. Accordingly, the closest dots D10 and D9 pull the pole teeth KA' in a direction opposite to the direction of advance. Therefore, the thrust in the direction of advance and the pullback force in the reverse direction match each other perfectly and the first yoke Y1 as a whole is balanced. That is, a thrust branched magnetic flux portion d is generated in the air gap between the pole teeth KA of the first branched magnetic path leg A and the closest dots D15 and D14, while a pullback force branched magnetic flux portion c is generated in the air gap between the pole teeth KA' of the second branched magnetic path leg A' and the closest dots D10 and D9, so

the first yoke Y1 itself becomes a stable point of the magnetic attraction potential.

Next, as shown in FIG. 12B, if an A-phase current of the illustrated polarity is supplied to only the terminals of the first and second A-phase excitation coils CA and CA' of the first yoke Y1, the air gap between the pole teeth KA of the first branched magnetic path leg A and the closest dots D15 and D14 switches from what had been the thrust branched magnetic flux portion d immediately before to the concentrated magnetic flux portion a comprised of the bias magnetic flux plus the alternating magnetic flux from the second excitation coil CA superposed, while the pole teeth KA' of the second branched magnetic path leg A' switch from the pullback branched magnetic flux portion c to the extinguished magnetic flux portion b, so the closest dots D15 and D14 strongly magnetically draw the pole teeth KA and advancing thrust occurs at the movable member 20. On the other hand, a branched magnetic flux to form the concentrated magnetic flux at the first branched magnetic path leg A of the first yoke Y1 through the inside of the platen 10 passes through the first and second branched magnetic path legs B and B' of the second yoke Y2. The pole teeth KB of the first branched magnetic path leg B switch from the extinguished magnetic flux portion b to the thrust branched magnetic flux portion d, while the pole teeth KB' of the second branched magnetic path leg B' switch from the concentrated magnetic flux portion a to the pullback branched magnetic flux

portion c. Therefore, due to the switching of the two-phase current, the movable member 20 advances by exactly  $P/4$ . If including the excitation patterns of FIGS. 12C and 12D, with a two-phase current, there are four excitation patterns of the excitation coils, so by one round of the excitation patterns, the movable member 20 advances four times and proceeds by exactly one pitch worth of distance. In the process of the switching of the two-phase current, a thrust force is generated at the pole teeth moving from the thrust branched magnetic flux portion d to the concentrated magnetic flux portion a.

To realize a planar linear motor having a movable member which moves planarly in the Y-axis and Y-axial direction using such a Sawyer linear motor, for example, as seen in Japanese Unexamined Patent Publication (Kokai) No. 9-261944, as shown in FIG. 13 and FIG. 14, there are provided a platen 10 formed on the platen surface with square-top platen dots D arranged in a matrix and a composite movable member comprised of X-axis movable members 20 having stripe-shaped projecting pole teeth KA and KA' (KB and KB') parallel to the Y-axis and able to move in only the X-axial direction and Y-axis movable members 20Y having stripe-shaped projecting pole teeth KA and KA' (KB and KB') parallel to the X-axis and able to move in only the Y-axial direction - all connected by a support plate 30 in an in-planar perpendicular relationship.

Further, to reduce the vibration or pulsation of the movable members 20X (20Y) during the advance, as shown in FIG. 15, the

yokes Y1 and Y2 may be given three branched magnetic path legs, the mutually independent phase excitation coils CU, CV, and CW (CU', CV', and CW') wound around the branched magnetic path legs U, V, and W (U', V', and W'), and a three-phase current supplied to these coils.

As a field of use of the above planar linear motor, for example, there is known a device mounting system providing a movable member moving planarly at the bottom surface of a platen held suspended down with an actuator for sliding in the normal direction of the bottom surface of the platen while holding an electronic device and inserting the electronic device into a through hole etc. of a substrate arranged under the platen.

The platen serving as the stator essential for the planar linear motor is formed on its surface with platen dots arranged in a matrix etc., so is comprised of a single thick plate magnetic material (thick steel plate) formed of a block material. Therefore, if this thick plate magnetic material is used as the platen, an eddy current naturally occurs due to the magnetic flux passing through the inside of the platen, so the AC magnetizing characteristic is poor and the power loss (iron loss) large and therefore it is difficult to obtain a high speed, high thrust force movable member and a large current capacity is required. As will be understood from the characteristic curve  $\alpha$  of the dependency of the thrust force versus speed shown in FIG. 16, the higher the frequency the driving periodic current (current pulse) is made and the higher the speed of the advance, the more rapidly

the thrust force falls and the much worse the efficiency (speed x thrust force/power consumption) becomes.

The present inventors took note of the fact that it is possible to suppress the occurrence of the eddy force and realize a high speed, high thrust, and high efficiency planar linear motor by using a stacked member comprised of a plurality of magnetic sheets (for example, a thickness of not more than 1 mm), using the parallel sheet edge surfaces of the stacked member (surface where edges of plurality of sheets appear in parallel) as the platen, and forming the platen dots arranged in a matrix by etching etc. the platen surface. Since an eddy current does not easily pass through the stacked interfaces (joined surfaces) of the magnetic sheets, the current resistance becomes higher and occurrence of an eddy current can be suppressed, so it is expected to be possible to realize a high speed, high thrust, high efficiency planar linear motor.

By making the row of pole teeth of a monoaxial movable member and the row of closest platen dots facing the same match and making the concentrated magnetic flux portion, extinguished magnetic flux portion, and branched magnetic flux portion (thrust, branched magnetic flux portion and pullback branched magnetic flux portion) move in a cyclic manner along the row direction in the magnetic circuit formed in the plane including the two rows, the monoaxial movable member advances along the row direction, so when the direction of arrangement of the pole tooth row of the monoaxial movable member and row of closest dots is the sheet

edge direction of the magnetic sheets, the magnetic circuit for the  
advancing magnetic flux is formed in the thicknesses of the  
magnetic sheets in parallel to the joined surfaces, so advance of a  
monoaxial movable member in the sheet edge direction becomes  
possible and the above advantages can be obtained.

The magnet flux in the stacked member, however, is refracted  
or blocked at the joined surfaces and the magnetic resistance is  
high, so it is not actually possible to form a magnetic circuit for an  
advancing magnetic flux along the normal direction of the joined  
surfaces and advance of the monoaxial movable member in the  
normal direction of the joined surfaces (direction perpendicular to  
the sheet edge direction) is impossible. Therefore, up until now,  
everyone has given up on development of a planar linear motor  
using a stacked member as a platen.

Therefore, in view of the above problem, the object of the  
present invention is to realize a monoaxial movable member giving  
thrust in the normal direction of the joined surfaces of a stacked  
member and thereby enabling utilization of the stacked member of  
the magnetic sheets as a platen and provide a high speed, high  
thrust, high efficiency linear motor.

#### DISCLOSURE OF INVENTION

To solve the above problem, the means devised by the  
present invention is to form a magnetic circuit for generating an  
advancing magnetic flux (concentrated magnetic flux and  
branched magnetic flux) for the movable member along the sheet

edge direction of the stacked member and causing magnetic  
coupling between one set of pole teeth of the movable member  
and the platen dots in the normal direction of the joined surfaces of  
the stacked member by arranging staggered one set of pole teeth  
5 in a predetermined spatial phase relationship within one pitch in the  
normal direction of the joined surfaces.

That is, the present invention provides a linear motor provided  
with a platen having a platen surface formed with a plurality of  
platen dots arranged in a matrix and an X-axis movable element  
10 having an pole tooth pattern having a set of at least  $2n$  (where  $n$  is  
an integer of 2 or more) pole teeth for generating an advancing  
magnetic flux with the closest dots among the platen dots, wherein  
the platen has the parallel sheet edge surfaces of the stacked  
member comprised of the plurality of magnetic sheets stacked  
15 together as the platen and wherein the  $2n$  number of magnetic  
teeth of the pole tooth pattern are arranged laterally in equal  
spatial phase relation with the closest dots arranged in the sheet  
edge direction (Y-direction) of the magnetic sheets. Further, the  $2n$   
number of pole teeth of the pole tooth pattern are arranged  
20 staggered within one dot pitch ( $P$ ) in the normal direction of the  
joined surfaces of the magnetic sheets. The spatial phase held with  
respect to the closest dot arranged in the normal direction is shifted  
by increments of the spatial phase difference ( $P/2n$ ). That is, the  
spatial phases held by the pole teeth with respect to the closest  
25 dots, when any spatial phase is  $p$ , are assigned as  $p-P/4$ ,  $p$ ,  $p+P/4$ ,

and  $p+P/2$  when  $n=2$ , as  $p-P/3$ ,  $p-P/6$ ,  $p$ ,  $p+P/6$ ,  $p+P/3$ , and  $p+P/2$  when  $n=3$ , and as  $p-3P/8$ ,  $p-P/4$ ,  $p-P/8$ ,  $p$ ,  $p+P/8$ ,  $p+P/4$ ,  $p+3P/8$ , and  $p+P/2$  when  $n=4$ .

According to this configuration, since all of the  $2n$  number of pole teeth of the pole tooth pattern have spatial phases held with respect to the closest dots arrayed in the sheet edge direction (Y-axial direction) of magnetic sheet, the X-axis movable member does not receive a thrust force to the Y-axial direction, but the  $2n$  number of pole teeth of the pole pattern of the X-axis movable member are arranged staggered shifted in phase in one dot pitch  $P$  in the normal direction of the joined surfaces of the magnetic sheets, so the magnetic circuit for the advancing magnetic flux is formed along the sheet edge direction of the stacked member. Further, the  $2n$  number of pole teeth of the pole pattern of the X-axis movable member have spatial phases held with respect to the closest dots arranged in the normal direction of the joined surface of the magnetic sheets shifted by exactly increments of the spatial phase difference  $(P/2n)$ , so magnetic couplings are caused with the closest dots arranged in the X-axial direction, the thrust force in the X-axial direction acts successively on the  $2n$  number of pole teeth of the pole tooth pattern laterally elongated in the Y-axial direction due to the cycle of combination of the concentrated magnetic flux and branched magnetic flux, and the X-axis movable member moves translationally in the X-axial direction due to so-called "crawling motion".

In this way, since it is possible to realize a monoaxial movable member giving thrust in the normal direction of the joined surfaces of the stacked member, it is possible to realize utilization of a stacked member of magnetic sheets as a platen and possible to provide a high speed, high thrust, high efficiency linear motor. The thrust force acts on the pole teeth switching from the branched magnetic flux to the concentrated magnetic flux, but the branched magnetic flux and concentrated magnetic flux occur at pole teeth of different yokes, so a rotational moment acting on the X-axis movable member occurs alternately in the forward and reverse directions. The higher the speed of movement, however, the smaller the ratio of the rotational vibration with respect to the speed of travel.

The pole teeth where the extinguished magnetic flux portion occurs differs the most, that is, half of a pitch, among the pole teeth from the pole teeth where the concentrated magnetic flux occurs. In the case of a platen using a magnetic sheet having a thickness of within half a pitch, the magnetic circuit formed along the sheet edge direction inherently finds it hard to hold magnetic couplings with pole teeth where extinguished magnetic flux parts occur, so there is no need to generate an alternating magnetic flux of a strength exactly extinguishing the bias magnetic flux and the degree of freedom of design is increased. In the case of a two-phase linear motor, the spatial phase difference held by an pole tooth of the concentrated magnetic flux portion and the pole teeth

of the pair of branched magnetic fluxes with respect to the closest dots is  $P/4$ , while the spatial phase difference held by the pole tooth of one branched magnetic flux and the pole tooth of the other branched magnetic flux is  $P/2$ . In the case of a three-phase linear motor, the spatial phase difference held by an pole tooth of the concentrated magnetic flux and the pole teeth of the pair of branched magnetic fluxes with respect to the closest dots is  $P/6$ , while the spatial phase difference of the pole tooth of one branched magnetic flux and the pole tooth of the other branched magnetic flux with respect to the closest dots is  $P/3$ . Therefore, in the case of a three-phase linear motor, it is preferable to use a magnetic sheet with a thickness of not more than  $1/3$  of the pitch. In general, in the case of an  $n$ -phase linear motor, it is preferable to use a magnetic sheet having a thickness of not more than  $1/n$  of the pitch. The greater the number of phases, the thinner the sheets. With three or more phases, magnetic coupling is hard to occur at both of the pair of pole teeth where the weak branched magnetic flux occurs, so the excess magnetic coupling consumed in stopping the progression is cut off and can be put to use in the thrust force of the progression. Rather, a higher efficiency can be expected from the X-axis movable member giving thrust in the perpendicular direction compared with the Y-axis movable member giving thrust in the sheet edge direction. Therefore, the present invention is not limited to the X-axis movable member of a 2D planar linear motor and has sufficient value of use as a one-dimensional linear motor

comprised of a platen using a stacked member and a monoaxial movable member giving thrust in a normal direction of the joined surfaces of the stacked member. Further, since the platen is a stacked member of magnetic sheets, it may be a stacked member with plastic or other nonmetallic materials sandwiched between dots in the X-axial direction. Further, it is not necessary to provide recesses between the dots. The platen can also be fabricated easily. Further, the leakage magnetic flux can be reduced and a higher efficiency can be contributed to.

Note that the spatial phase relationship between the set of poles of the movable member side and the set of closest dots of the platen side is relative, so instead of giving a staggered arrangement in the phase relationship among the pole teeth of the movable member, it is also possible to give a staggered arrangement in the phase relationship among the platen dots arranged in the X-axial direction of the platen side.

When the X-axis movable member has a group of patterns comprised of a pole tooth pattern arranged repeatedly in the normal direction of the joined surfaces, it is possible to obtain stable travel and high output of the X-axis movable member.

A pair of patterns are formed comprised of the above pole tooth pattern as a first pole tooth pattern and a second pole tooth pattern separated in the normal direction from the first pole tooth pattern. The staggered arrangement of the first pole tooth pattern and the staggered arrangement of the second pole pattern are line

symmetric about the X-direction line passing through the pattern center. Both staggered arrangements are in spatial phase relationship held with respect to the closest dots arranged in the normal direction of the joined surfaces of the magnetic sheets of the first pole tooth pattern and the second tooth pattern, respectively. Since a forward and reverse rotational moment simultaneously act on the X-axis movable member, the rotational moments are canceled out and it is possible to eliminate rotational vibration.

When the X-axis movable member has a group of patterns comprised of the first pole pattern and second pole pattern arranged alternately repeatedly in the normal direction of the joined surfaces, it is possible to again obtain stable travel and high output of the X-axis movable member.

It is preferable to configure the planar linear motor by the above X-axis movable member and Y-axis movable member moving in the sheet edge direction of the magnetic sheets connected in an in-plane perpendicular relationship, but here two X-axis movable members and two Y-axis movable members are arranged diagonally with respect to the center point of the plane of the composite movable member and arrange the pole tooth pattern of one X-axis movable member and the pole tooth pattern of the other X-axis movable member line symmetrically with respect to the X-direction line passing through the center point of the plane. The rotational moment about the center point of the plane of the composite movable member acts simultaneously in the forward

and reverse directions, the rotational moments are canceled out,  
and the rotational vibration of the composite movable member as  
a whole can be eliminated and therefore stable travel in the X-axial  
direction and Y-axial direction can be realized from low speed  
5 travel to high speed travel.

#### BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a perspective view of the general configuration of a  
2-phase planar linear motor according to a first embodiment of the  
present invention.

10 FIG. 2 is a perspective view of an X-axis movable member in  
the motor.

FIG. 3 is a plan view of the spatial phase relationship between  
the pole teeth of the X-axis movable member and platen dots.

FIG. 4 is a side view of an X-axis movable member seen in the  
15 X-axial direction.

FIGS. 5A to 5D are sectional views of the states cut along the  
line B'-B', line B-B, line A'-A', and line A-A in FIG. 3.

FIG. 6 is a schematic plan view of an X-axis movable member  
having a group of patterns having both a first pole tooth pattern  
20 and second pole tooth pattern.

FIG. 7 is a plan view of the relative arrangement of X-axis  
movable members and Y-axis movable members.

FIG. 8 is a perspective view of the schematic configuration of  
an X-axis movable member in a 3-phase planar linear motor  
25 according to a second embodiment of the present invention.

FIG. 9 is a plan view of the relative spatial phase between the pole teeth of the X-axis movable member and platen dots.

FIG. 10 is a side view of the X-axis movable member seen in the X-axial direction.

FIGS. 11A to 11F are sectional views of the states cut along the line W'-W', line V'-V', line U'-U', line W-W, line V-V, and line U-U in FIG. 9.

FIGS. 12A to 12D are progressive views of the operation for explaining the principle of a Sawyer motor (two-phase linear motor).

FIG. 13 is a perspective view of the schematic configuration of a conventional 2-phase planar linear motor.

FIGS. 14A is a plan view of a two-phase planar linear motor in FIG. 13, FIG. 14B is a right side view of the same two-phase planar linear motor, and FIG. 14C is a front view of the same two-phase linear motor.

FIG. 15A is a plan view of a conventional three-phase planar linear motor, FIG. 15B is a right side view of the same three-phase planar linear motor, and FIG. 15C is a front view of the same three-phase linear motor.

FIG. 16 is a graph of a comparison of the characteristic curves of the dependency of the thrust versus the speed of the movable member in the cases where the platen is a block material and is a stacked member.

#### BEST MODE FOR CARRYING OUT THE INVENTION

##### First Embodiment

FIG. 1 is a perspective view of the general configuration of a 2-phase planar linear motor according to a first embodiment of the present invention; FIG. 2 is a perspective view of an X-axis movable member in the motor; FIG. 3 is a plan view of the spatial phase relationship between the pole teeth of the X-axis movable member and platen dots; FIG. 4 is a side view of an X-axis movable member seen in the X-axial direction; and FIGS. 5A to 5D are sectional views of the states cut along the line B'-B', line B-B, line A'-A', and line A-A in FIG. 3. Note that in FIG. 1 to FIG. 3, portions the same as those in FIG. 13 and FIG. 14 are assigned the same reference numerals and explanations thereof will be omitted.

The two-phase planar linear motor of this embodiment is comprised of a platen 50 having a platen surface 51 formed with a plurality of platen dots D arranged in a matrix and a composite movable member 70 comprised of two X-axis movable members 60X and two Y-axis movable members 20Y connected by a support plate 30 in an in-plane perpendicular relationship. The composite movable member 70 has a pressurized air ejection port (not shown) and moves planarly while floating slightly above the surface of the platen 50 by the blown pressurized air.

This two-phase planar linear motor is employed for example as an IC test handler. The IC test handler is provided with a contact transfer which holds an IC at the entry position by suction, moves it to a test position, then descends to continue to press down terminals of the IC on the IC socket for a predetermined time, then suitably

thereafter raises the IC and inserts it in an exit position. With this IC test handler, the platen 50 is supported suspended upside down from the illustrated state. The composite movable member 70 moves planarly along the platen surface directly under the platen 50 using the contrast transfer as a base.

The platen 50 is a stacked member comprised of a plurality of magnetic sheets T stacked together. As shown in FIG. 1 and FIG. 2, the parallel sheet edge surfaces are used as the platen surface 51. The magnetic sheets T are for example silicon steel sheets coated with insulating films of for example 0.35 to 0.5 mm thickness. The dot pitch of the platen dots D (one spatial period) is for example several mm.

Each of the Y-axis movable members 20Y is a movable member advancing in the sheet edge direction (Y-axial direction) of the magnetic sheets T. The first and second yokes Y1 (Y2), like in the past, have stripe-shaped projecting pole teeth KA and KA' (KB and KB') parallel with the X-axis.

The pole teeth  $KA_x$  and  $KA'_x$  ( $KB_x$  and  $KB'_x$ ) of the first and second branched magnetic path legs A and A' (B and B') of the first yoke Y1 of each of the X-axis movable members 60X are flat in the Y-axial direction as shown in FIG. 4 and have equal spatial phases with respect to the closest dots D arranged in the sheet edge direction of the magnetic sheets T. The lengths in the Y-axial direction of the pole teeth  $KA_x$  and  $KA'_x$  ( $KB_x$  and  $KB'_x$ ) are two pitches worth of length of the platen dots D. The intervals between

them are also two pitches worth of length. However, the pole teeth  $KA_x$  and  $KA'_x$  ( $KB_x$  and  $KB'_x$ ) are repeatedly arrayed for each dot pitch (one spatial period =  $P$ ) in the normal direction (X-axial direction) of the joined surfaces of the magnetic sheets  $T$  to form rows of teeth. As shown in FIG. 3 and FIG. 5, the pole teeth  $KA_x$  and  $KA'_x$  ( $KB_x$ ,  $KB'_x$ ) comprising a laterally arranged set (pole tooth pattern) fitting in one pitch are arranged staggered within one dot pitch in the normal direction of the joined surfaces of the magnetic sheets  $T$ . Further, the spatial phases held with respect to the closest dots arranged in the normal direction are shifted by increments of the spatial phase difference ( $P/4$ ).

In the pole tooth pattern 61 surrounded by the two-dot chain line in FIG. 3, the pole tooth  $KA_x$  is in register with the closest dot  $D$ , a concentrated magnetic flux portion a occurs in the air gap as shown in FIG. 5D, the pole tooth  $KA'_x$  is staggered by exactly half a pitch with respect to the closest dot  $D$ , the air gap as shown in FIG. 5C becomes an extinguished magnetic flux portion b, the pole tooth  $KB_x$  is staggered advanced by exactly  $P/4$  from the closest dot  $D$ , the air gap shown in FIG. 5B becomes a pullback branched magnetic flux portion c, the pole tooth  $KB'_x$  is staggered delayed by exactly  $P/4$  from the closest dot  $D$ , and the air gap shown in FIG. 5A becomes the thrust branching magnetic flux portion d. Each X-axis movable member 60X has a group of patterns comprised of the above group of pole tooth patterns 61 repeated in the X-axial direction at a one-pitch period.

The pole teeth  $KA_x$  and  $KA'_x$  ( $KB_x$  and  $KB'_x$ ) of each pole tooth pattern 61 all have equal spatial phases with respect to the closest dots D arranged in the sheet edge direction (Y-axial direction) of the magnet sheets T, so while the X-axis movable member 60X does not receive thrust force in the Y-axial direction, the pole teeth  $KA_x$  and  $KA'_x$  ( $KB_x$  and  $KB'_x$ ) fit within one pitch in the X-axial direction, so a magnetic circuit for the advancing magnetic flux is formed along the sheet edge direction of the stacked member. In the state shown in FIG. 3 and FIG. 5 (excitation state due to A-phase current), the pole tooth  $KB'_x$  generates a thrust branched magnetic flux portion d, so in the process of switching from the A-phase current to the B-phase current, a thrust force acts on the pole tooth  $KB'_x$  in the X-axial direction, in the second switching process, a thrust force acts on the pole tooth  $KA'_x$  in the X-axial direction, in the third switching process, a thrust force acts on the pole tooth  $KB_x$  in the X-axial direction, and in the fourth switching process, a thrust force acts on the pole tooth  $KA_x$  in the X-axial direction. An X-axial direction thrust force acts successively on the four pole teeth of each pole tooth pattern 61 laterally elongated in the Y-axial direction by the cycle of combination of the concentrated magnetic flux portion a and branched magnetic flux portion cd, whereby the X-axis movable member 60X moves translationally in the X-axial direction by a so-called "crawling motion". Of course, it moves translationally in the X-axial direction even in the case of a platen comprised of a block material.

In this way, since it is possible to realize an X-axis movable member 60X giving thrust in the normal direction of the joined surfaces of the stacked member, it is possible to realize utilization of a stacked member of magnetic sheets T as the platen 50. As will be understood from the characteristic curve  $\beta$  of the dependency of the thrust force versus speed shown in FIG. 16, even if making the frequency of the drive period current (current pulse) higher and making the speed of advance higher, the thrust force does not fall that much up to the high speed region (2 m/sec). Therefore, it becomes possible to realize a high speed, high thrust, and high efficiency linear motor.

The spatial phase relationship between the X-side pole teeth  $KA_x$  and  $KA'_x$  ( $KB_x$  and  $KB'_x$ ) of each X-axis movable member 60X and the platen dots D arranged in the X-axial direction at the platen 50 side is relative, so instead of giving a staggered arrangement among the pole teeth  $KA_x$  and  $KA'_x$  ( $KB_x$  and  $KB'_x$ ), it is possible to give a staggered arrangement among the platen dots D arranged in the X-axial direction at the platen 50 side. The number of dots on the platen surface, however, is enormous, so this would be disadvantageous in the production of the platen 50. It would be realizable however in the case of a platen of a small area or with the development of high precision techniques for production of platens.

Since a thrust force acts on the pole teeth switching from a thrust branched magnetic flux portion  $d$  to a concentrated

magnetic flux portion a, the thrust branched magnetic flux portion d and the concentrated magnetic flux portion a occur at the pole teeth of the opposite yokes, so a rotational moment acting on the X-axis movable member 60X occurs in alternately forward and reverse directions and the X-axis movable member 60X moves translationally along with the rotational vibration. The higher the speed of travel, however, the smaller the ratio of the rotational vibration with respect to the speed of travel.

Here, considering the relationship between the dot pitch P of the platen 50 (same as pitch of pole teeth of X-axis movable member 60X) and the magnetic sheets T, the thickness of the magnetic sheets T may be less or more than the dot pitch, but for achieving high speed, high thrust, and high efficiency, it is preferably less than the dot pitch. Taking note of the pole teeth where the extinguished magnetic flux portion b occurs in the magnetic circuit, the pole teeth have no direct relevance to the thrust force or stability of the movable member. They are just so to say assigned in series. Further, the pole teeth where the extinguished magnetic flux portion b occurs differ the most among the pole teeth from the pole teeth where the concentrated magnetic flux portion a occurs. There is a spatial phase difference of half a pitch. Therefore, as in this embodiment, in the case of a platen 50 using magnetic sheets T having a thickness within half of a pitch, the magnetic circuit formed along the sheet edge direction inherently finds it hard to hold magnetic coupling with pole teeth where the

extinguished magnetic flux portion occurs, so there is no need to generate an alternating magnetic flux of a strength exactly extinguishing the bias magnetic flux and the degree of freedom of design is increased. This is also an advantage of using a stacked member as a platen. Further, since the platen 50 is a stacked member of magnetic sheets T, it may be a stacked member with plastic or other nonmetallic materials sandwiched between dots in the X-axial direction. Further, it is not necessary to provide recesses between the dots. The platen can also be fabricated easily. Further, the leakage magnetic flux can be reduced and a higher efficiency can be contributed to.

The group of pole teeth shown in FIG. 3 corresponds to an array of for example the pole tooth pattern 61 among the four types of pole tooth patterns repeated at one-pitch intervals in the X-axial direction. Here, if the pole tooth pattern 61 is made the first pole tooth pattern, and for example, as shown in FIG. 6, if a second pole tooth pattern 62 relating to the pole teeth  $Ka_x$ ,  $Ka'_x$ ,  $Kb_x$ , and  $Kb'_x$  is formed apart from the first pole tooth pattern in the X axial direction, and if the staggered arrangement of the spatial phase relationship held with respect to the closest dots arranged in the X-axial direction of the pole teeth  $Ka_x$ ,  $Ka'_x$ ,  $Kb_x$ ,  $Kb'_x$  of the first pole tooth pattern and the staggered arrangement are line symmetric with respect to the X-direction line L, passing through the pattern center, a forward and reverse rotational moment act simultaneously on the X-axis movable member 60X, so the rotational moments are

canceled out and the rotational vibration can be eliminated. This is because the pole tooth  $KB'_x$  of the first pole tooth pattern and the pole tooth  $Ka_x$  of the second pole tooth pattern 62, the pole tooth  $KB_x$  of the first pole tooth pattern 61 and the pole tooth  $Ka'_x$  of the second pole tooth pattern 62, the pole tooth  $KA'_x$  of the first pole tooth pattern and the pole tooth  $Kb_x$  of the second pole tooth pattern 62, and the pole tooth  $KA_x$  of the first pole tooth pattern 61 and the pole tooth  $Kb'_x$  of the second pole tooth pattern 62 have the same spatial phases with respect to the closest dots.

In this embodiment, as explained above, X-axis movable members 60X and Y-axis movable members 20Y are connected in an in-plane perpendicular relationship to form a composite movable member 70. As shown in FIG. 7, the two X-axis movable members 60X and two Y-axis movable members 20Y are arranged diagonally with respect to the center point O of the plane of the composite movable member 70, and the pole tooth patterns 61 of one of the X-axis movable members 60X (branched magnetic path legs A, A', B, B') and the pole tooth patterns 61 of the other of the X-axis movable members 60X (branched magnetic path legs A, A', B, B') are arranged to be line symmetric about the X-direction line  $L_2$  passing through the center point O of the plane. The rotational moment about the center point O of the plane of the composite movable member 70 acts simultaneously in the forward and reverse directions, the rotational moments are canceled out, and the rotational vibration of the composite movable member 70 as a

whole can be eliminated and therefore stable travel in the X-axial direction and Y-axial direction can be realized from low speed travel to high speed travel.

### Second Embodiment

FIG. 8 is a perspective view of the schematic configuration of an X-axis movable member in a three-phase planar linear motor according to a second embodiment of the present invention, FIG. 9 is a plan view of the relative spatial phase between the pole teeth of an X-axis movable member and platen dots, FIG. 10 is a side view of an X-axis movable member seen in the X-axial direction, and FIGS. 11A to 11F are sectional views of the states cut along the line W'-W', line V'-V', line U'-U', line W-W, line V-V, and line U-U in FIG. 9. Note that in FIG. 8 to FIGS. 11A to 11F, portions the same as in FIG. 15 are assigned the same reference numerals and explanations thereof are omitted. Further, portions the same as in the first embodiment will not be alluded to.

The six pole teeth  $KU_x$ ,  $KV_x$ ,  $KW_x$ ,  $KU'_x$ ,  $KV'_x$  and  $KW'_x$  of an pole tooth pattern 81 in one pitch in the X-axial direction in an X-axis movable member 80W of the present embodiment are arranged staggered in the one-dot pitch P in the normal direction of the joined surfaces of the magnetic sheets T. Further, they have spatial phases held with respect to the closest dots arranged in the normal direction shifted by increments of the spatial phase difference  $(P/6)$ . The pole tooth  $KU_x$  in the pole tooth pattern 81 surrounded by the two-dot chain line in FIG. 9 is in register with the closest dot D. A

concentrated magnetic flux portion a occurs in the air gap shown in FIG. 11F and the pole tooth  $KV_x$  is staggered advanced by exactly  $P/3$  with respect to the closest dot D; in FIG. 11E, the air gap becomes the weak branched magnetic flux not shown and the pole tooth  $KW_x$  is staggered delayed by exactly  $P/3$  from the closest dot D; and in FIG. 11D, again a weak branched magnetic flux results not shown in the air gap. The pole tooth  $KU'_x$  is staggered delayed by exactly half a pitch with respect to the closest dot. As shown in FIG. 11C, the air gap becomes the extinguished magnetic flux portion b and the pole tooth  $KV'_x$  is staggered delayed by exactly  $P/6$  from the closest dot D, the air gap shown in FIG. 11B becomes the thrust branched magnetic flux portion d and the pole tooth  $KW'_x$  is staggered advanced by exactly  $P/6$  with respect to the closest dot D, and the air gap shown in FIG. 11A becomes a pullback branched magnetic flux portion c. The X-axis movable member 80X has a group of patterns comprised of the pole tooth pattern 81 repeated in the X-axial direction at one-pitch intervals.

In this three-phase planar linear motor, a concentrated magnetic flux portion a and a branched magnetic flux portion cd separately are generated at the yokes Y1 and Y2. This is because the excitation coils of the same phase are wound separately around the yokes Y1 and Y2. The rest of the configuration of the three-phase planar linear motor of this embodiment can use the configuration of the first embodiment.

Even in such a three-phase planar linear motor, in the same

way as the first embodiment, it is possible to realize an X-axis  
movable member 80X giving thrust in the normal direction of the  
joined surfaces of the stacked member, so use of the stacked  
member of the magnetic sheets T as the platen 50 can be made  
practical and realization of a high speed, high thrust, and high  
efficiency planar motor becomes possible.

The pole teeth where the extinguished magnetic flux portion  
b occurs differ the most, that is, half of a pitch, among the pole  
teeth from the pole teeth where the concentrated magnetic flux  
portion a occurs. In the case of a platen using a magnetic sheet  
having a thickness of within half a pitch, the magnetic circuit  
formed along the sheet edge direction inherently finds it hard to  
hold magnetic coupling with pole teeth where the extinguished  
magnetic flux portion occurs, so there is no need to generate an  
alternating magnetic flux of a strength exactly extinguishing the bias  
magnetic flux and the degree of freedom of design is increased. In  
the case of a three-phase planar linear motor of this embodiment,  
the spatial phase difference held by a pole tooth of a  
concentrated magnetic flux and the pole teeth of the pair of  
branched magnetic fluxes with respect to the closest dots is  $P/6$ ,  
while the spatial phase difference of the pole tooth of one  
branched magnetic flux portion c and the pole tooth of another  
branched magnetic flux portion d with respect to the closest dots is  
 $P/3$ . Therefore, in the case of a three-phase linear motor, it is  
preferable to use a magnetic sheet with a thickness of not more

than 1/3 of the pitch. Magnetic coupling with the extinguished  
magnetic flux part b is hard to occur due to the joined surfaces, the  
invalid magnetic flux can be reduced, and simultaneously  
magnetic coupling is hard to occur at both of the pair of pole teeth  
5 (KV<sub>x</sub> and KW<sub>x</sub> in FIG. 11) where the thin branched magnetic fluxes  
occur, so the magnetic coupling consumed in stopping the  
progression is cut off and can be put to use in the thrust force of the  
progression.

Note that it is of course also possible to realize a four-phase or  
10 higher linear motor.

#### INDUSTRIAL APPLICABILITY

As explained above, the linear motor according to the  
present invention has a monoaxial movable member giving thrust in  
a normal direction of the joined surfaces of the stacked member, so  
15 use of the stacked member of the magnetic sheets as the platen  
can be made practical and a high speed, high thrust, and high  
efficiency motor can be provided, so is suitable for use not only in a  
device mounting system, but also an IC test handler or other various  
types of equipment or machinery.